

# Ideas for future liquid Argon detectors\*

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We outline a strategy for future experiments on neutrino and astroparticle physics based on the use, at different detector mass scales (100 ton and 100 kton), of the liquid Argon Time Projection Chamber (LAr TPC) technique. The LAr TPC technology has great potentials for both cases with large degree of interplay between the two applications and a strong synergy. The ICARUS R&D programme has demonstrated that the technology is mature and that one can build a large ( $\sim 1$  kton) LAr TPC. We believe that one can conceive and design a very large mass LAr TPC with a mass of 100 kton by employing a monolithic technology based on the use of industrial, large volume cryogenic tankers developed by the petro-chemical industry. We show a potential implementation of a large LAr TPC detector. Such a detector would be an ideal match for a Superbeam, Betabeam or Neutrino Factory, covering a broad physics program that could include the detection of atmospheric, solar and supernova neutrinos, and search for proton decays, in addition to the rich accelerator neutrino physics program. In parallel, physics is calling for another application of the LAr TPC technique at the level of 100 ton mass, for low energy neutrino physics and for use as a near station setup in future long baseline neutrino facilities. We present here the main physics objectives and outline the conceptual design of such a detector.

## 1. The liquid Argon TPC technique

Among the many ideas developed around the use of liquid noble gases, the Liquid Argon Time Projection Chamber (LAr TPC), conceived and proposed at CERN by C. Rubbia in 1977 [1], certainly represented one of the most challenging and appealing designs. The technology was proposed as a tool for uniform and high accuracy imaging of massive detector volumes. The operating principle of the LAr TPC was based on the fact that in highly purified LAr ionization tracks could indeed be transported undistorted by a uniform electric field over distances of the order of meters. Imaging is provided by wire planes placed at the end of the drift path, continuously sensing and recording the signals induced by the drifting electrons. Liquid Argon is an ideal medium since it provides high density, excellent properties (ionization, scintillation yields) and is intrinsically safe and cheap, and readily available any-

where as a standard by-product of the liquefaction of air.

Non-destructive readout of ionization electrons by charge induction allows to detect the signal of electrons crossing subsequent wire planes with different orientation. This provides several projective views of the same event, hence allowing for space point reconstruction and precise calorimetric measurement.

The detector performance can be summarized as (1) a tracking device with precise event topology reconstruction; (2) momentum estimation via multiple scattering; (3) measurement of local energy deposition ( $dE/dx$ ), providing  $e/\pi^0$  separation (sampling typ.  $2\%X_0$ ), particle identification via range versus  $dE/dx$  measurement; (4) total energy reconstruction of the event from charge integration (the volume can be considered as a full-sampling, fully homogenous calorimeter) providing excellent accuracy for contained events.

The main technological challenges of this detection technique have been recently summarized elsewhere [2]. They mainly consisted in: (1) techniques of Argon purification, (2) oper-

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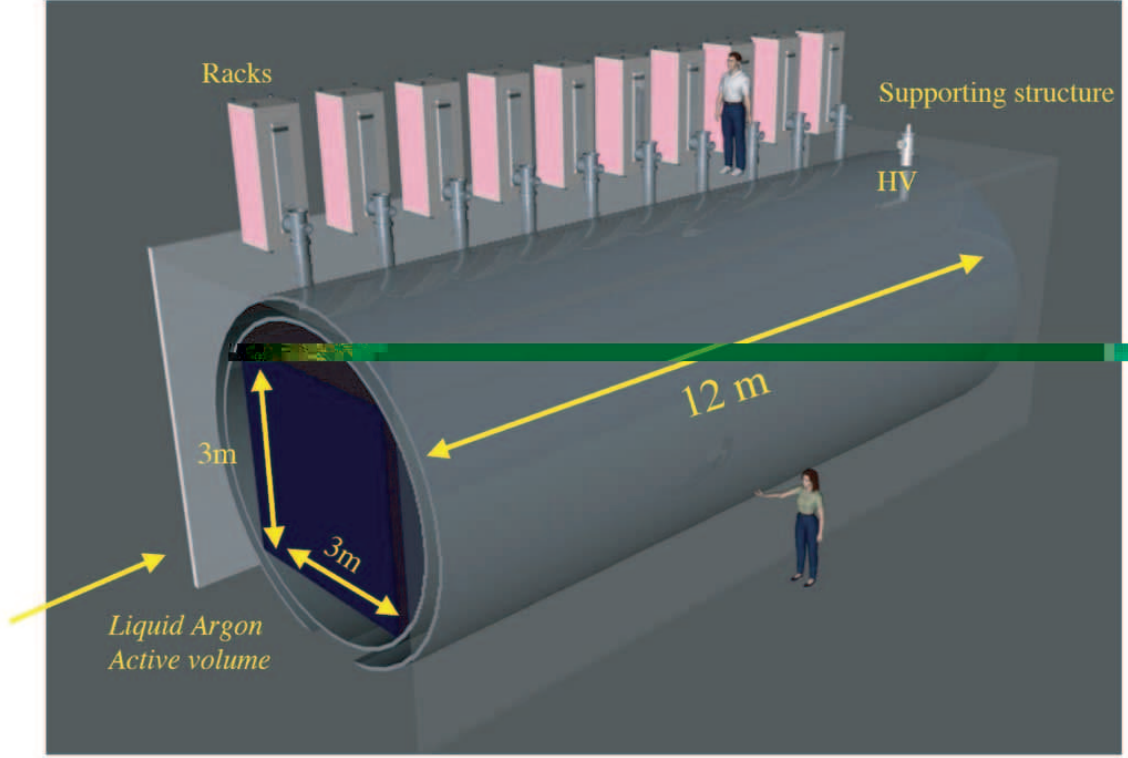


Figure 1. Conceptual design of a 100 ton liquid Argon TPC detector.

ation of wire chambers in cryogenic liquid and without charge amplification, (3) extremely low-noise analog electronics, (4) continuous waveform recording and digital signal processing.

The feasibility of this technology has been demonstrated by the extensive ICARUS R&D program, which included studies on small LAr volumes about proof of principle, LAr purification methods, readout schemes and electronics, as well as studies with several prototypes of increasing mass on purification technology, collection of physics events, pattern recognition, long duration tests and readout. The largest of these devices had a mass of 3 tons of LAr [3,4] and has been continuously operated for more than four years, collecting a large sample of cosmic-ray and gamma-source events. Furthermore, a smaller device with 50 l of LAr [5] was exposed to the CERN neutrino beam, demonstrating the high recognition capability of the technique for neutrino interaction events.

The realization of the 600 ton ICARUS detector culminated with its full test carried out at surface during the summer 2001 [2]. This test demonstrated that the LAr TPC technique can be operated at the kton scale with a drift length of 1.5 m. Data taking of about 30000 cosmic-ray triggers have allowed to test the detector performance in a quantitative way and results have been published in [6,7,8,9,10]. Transportation and installation at the Gran Sasso Underground Laboratory is currently on-going.

## 2. What the liquid Argon TPC provides

As already mentioned, the bubble-chamber-like event reconstruction capability provide simultaneously (1) a tracking device with unbiased imaging and reconstruction, and (2) a full sampling calorimetry. The detector is fully active, homogeneous and isotropic. The energy resolution is very good, both for en-

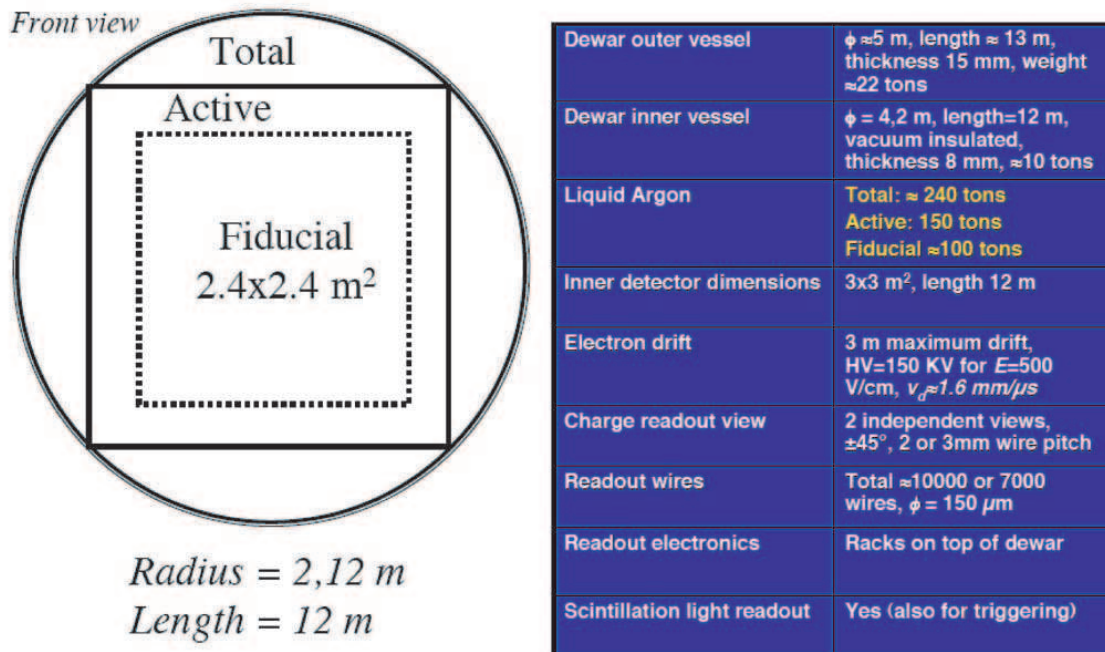


Figure 2. Preliminary parameters of a 100 ton liquid Argon TPC detector.

ergy (calorimetry) and for angular reconstruction (tracking). The energy resolutions of contained particles are  $\sigma/E = 11\%/\sqrt{E(\text{MeV})} \oplus 2\%$  for low energy electrons (measured [6]),  $\sigma/E \approx 3\%/\sqrt{E(\text{GeV})}$  for electromagnetic showers,  $\sigma/E \approx 30\%/\sqrt{E(\text{GeV})}$  for hadronic showers (pure LAr),  $\sigma/E \approx 17\%/\sqrt{E(\text{GeV})}$  for hadronic showers (TMG doped LAr). The chamber can be readily used in a broad energy range, from MeV up to multi-GeV's with high event reconstruction efficiency. At the same time, low thresholds for particle identification are possible given the high granularity. Combining  $dE/dx$  measurements and range it is possible to separate muons, pions, kaons, and protons. Separation of electrons from neutral pions, and of muons from pions are also highly efficient, owing to the imaging and multiple  $dE/dx$  measurements. Like bubble chambers, it is possible to operate a liquid argon TPC in a shallow depth (even though these are slow devices) owing to the high granularity which permits the separation of the signal from the background activity. Finally, it is possible to embed the detector in a magnetic field for charge

discrimination[13].

Implementations at different mass scales (e.g. from 100 tons to 100 ktons) are conceivable.

### 3. A 100 ton detector in a near station of a LBL experiment

#### 3.1. Tentative design

A 100 ton detector in a near-site of a long-baseline facility is a straight forward and very desirable application of the technique. For example, the approved T2K experiment in Japan[11] or other beams in the US might provide the ideal conditions to study with high statistical accuracy neutrino interactions on liquid Argon in the very important energy range around 1 GeV. This is a mandatory step in order to be able to handle high statistics provided by large detectors. A prototype of a 100 ton detector could provide a tool to study calorimetric (electromagnetic and hadronic) response in a charged particle beam or be readily placed in an existing neutrino beam.

A tentative layout of the detector is shown in Figure 1. The active liquid Argon volume is en-

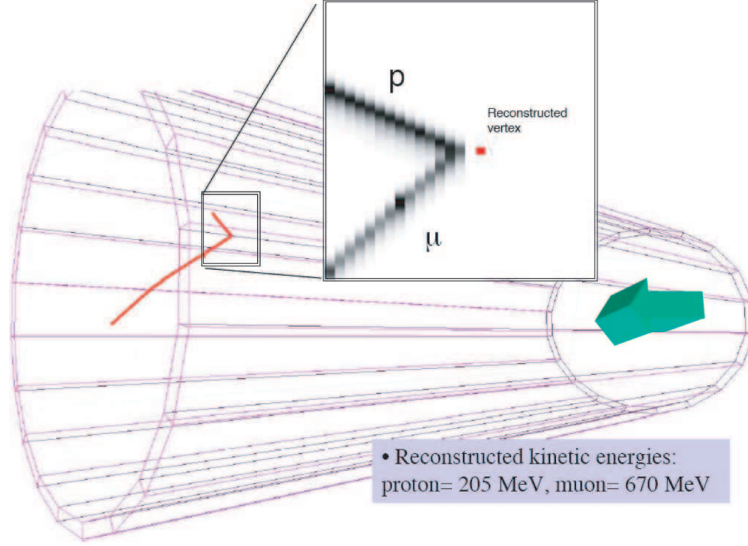


Figure 3. Reconstruction of a quasi-elastic event in a 150 ton liquid Argon volume.

visaged to be  $3 \times 3 \times 12 \text{ m}^3$ . The liquid Argon is stored in a cylindrical cryostat with vacuum insulation. Around the cryostat a supporting structure allows to install the electronic racks close to the signal feed-throughs located at the top of the dewar. Other services (e.g. high-voltage) are also located at the top. A preliminary list of parameters is given in Figure 2. The front view of the detector with the definition of the various liquid Argon subvolumes is also shown. A typical quasi-elastic muon neutrino interaction is shown in Figure 3.

We discuss in the following sections in more details the case of the T2K experiment.

### 3.2. The T2K project

The JHF-Kamioka neutrino project is a second generation long baseline neutrino oscillation experiment that probes physics beyond the Standard Model by high precision measurements of the neutrino masses and mixing. A high intensity narrow band neutrino beam is produced by secondary pions created by a high intensity proton synchrotron at JHF (JAERI). The neutrino energy is tuned to the oscillation maximum at  $\sim 1 \text{ GeV}$  for a baseline length of 295 km towards the world largest water Čerenkov detector, Super-Kamiokande.

The project is divided into two phases. In the first phase, the main physics goal is the precision measurement of neutrino oscillation with the 50 GeV PS of 0.77 MW beam power and Super-Kamiokande. The physics goal of the first phase is an order of magnitude better precision in the  $\nu_\mu \rightarrow \nu_\tau$  oscillation measurement ( $\delta(\Delta m_{23}^2) = 10^{-4} \text{ eV}^2$  and  $\sin^2 2\theta_{23}$  with 1% precision), a factor of 20 more sensitive search in the  $\nu_\mu \rightarrow \nu_e$  appearance ( $\sin^2 2\theta_{13} > 0.006$ ), and a confirmation of the  $\nu_\mu \rightarrow \nu_\tau$  oscillation or discovery of sterile neutrinos by detecting the neutral current events. During a second phase, the power of the neutrino beam could be increased and a new far detector could be considered[11].

### 3.3. The measurements at the near stations of T2K

The T2K long-baseline program foresees (1) one near station at 280 m, (2) an option for a second intermediate station at 2 km and (3) the far station composed by the existing Superkamiokande detector.

In order to achieve the challenging goals of the T2K program, the following items will need to be addressed:

1. For the disappearance experiment: in or-

der to determine precisely the  $\Delta m_{23}^2$  and  $\sin^2 2\theta_{23}$  parameters with small systematic errors, a very good knowledge of the neutrino beam will have to be reached.

2. For the appearance experiment: in order to understand precisely the beam associated backgrounds to the electron appearance search, a very good knowledge of (a) the intrinsic  $\nu_e$  component of the beam and (b) the  $\pi^0$  production in neutrino interactions in the GeV range will be mandatory.

We assume that the near detectors will be composed of different technologies, like in the case of the presently running K2K experiment[12], including both Water Cerenkov and “fine grained” detectors. There are plans for a 1 kton Water Cerenkov detector and other fine grain detectors. At the 2 km position, the rate in a 100 ton detector would be about 300'000 events per year. This is a unique location for a liquid Argon TPC, since this technique would allow to readily reach the required mass while keeping the fine granularity.

We give in the following a list of physics measurements that could be performed in the near stations with a liquid Argon detector:

(A) Measurement of  $\nu_\mu$  CC events: the liquid Argon TPC will provide an independent measurement of the “off-axis” flux. The excellent muon identification makes the selected sample very clean and the reconstruction will be unbiased. The low momentum detection threshold in LAr compared to Water Cerenkov allows for an independent classification and measurement of event samples in the GeV region. This will provide independent systematic on the  $nQE/QE$  ratio and on the energy scale[12]. In addition, the independent reconstruction effects in Water Cerenkov can be studied with the events recorded in the LAr and this will help in the understanding the systematic errors in extrapolating the 1 kton Water Cerenkov to SuperK. Finally, the energy independent detection and measurement efficiency for subGeV and multiGeV events in LAr will provide a measurement of the high energy muon neutrinos from kaon decays for an extra handle on the  $\nu_e$  component of the beam.

(B) Measurement of  $\nu$  NC events: the clean measurement of the  $\pi^0$  production will provide an independent systematic error on the  $NC/CC$  ratio. One can also address independently the coherent production by looking for the absence of tracks at the vertex. The clean  $e/\pi^0$  separation available thanks to the excellent event and particle identification plays here an important role.

(C) Measurement of intrinsic  $\nu_e$  CC events: the excellent event and particle identification give clean  $e/\mu$  and  $e/\pi^0$  separation with an unbiased reconstruction. This will provide an independent measurement of the  $\nu_e$  contamination, well separated from the  $\pi^0$  background. Combined with the NC background, it will yield independent and separated components  $\nu_e$  and  $\pi^0$  background at the far detector.

(D) Standard model neutrino interactions in the GeV region: the bubble-chamber like imaging will permit the study of neutrino interactions with high quality and given the flux and large mass with high statistics. This sample of events will allow the study of the DIS+resonance modeling, the QE modeling (form factors, ...), and the nuclear effects (binding, Fermi-motion, Pauli-exclusion, NN-correlations, PDF modifications, rescattering, ...).

We recall that the neutrino beam at JAERI is constructed as an “off-axis” beam with an angle between 2 and 3 degrees. While a lot of experimental knowledge has been acquired with the prediction of on-axis fluxes, there is no previous experience in the operation of off-axis beam. In particular, we note that the systematics associated to on- and off-axis beam could be quite different: (1) in an on-axis beam, the prediction of the neutrino flux requires a good knowledge of the meson spectrum yield and to lesser extent their angular distribution since the beam at the far location is very wide and the detector is placed at the maximum of the flux. On the other hand, an off-axis beam requires the knowledge of the meson spectrum with less precision, since in the ideal case of the Jacobian peak, the neutrino flux is actually independent of the parent meson momentum. Hence, the meson spectrum is less important. On the other hand, angular effects are most important, as can be appreciated by consid-

ering the modification in the neutrino spectrum when the beam angle is changed by 1 degree.

It appears natural that a conservative approach to the first ever performed off-axis experiment with the goals of measuring very precisely the oscillation parameters will require some level of redundancy.

#### 4. A 100 kton liquid Argon TPC detector with charge imaging, scintillation and Cerenkov light readout

A 100 kton liquid Argon TPC would deliver extraordinary physics output (sometimes called “megaton physics”), owing to better event reconstruction capabilities provided by the LAr technique. A 100 kton LAr TPC would represent one of the most advanced massive underground detectors built so far [14].

##### 4.1. Tentative design

A conceptual design for a 100 kton LAr TPC was first given in Ref. [15]. The basic design features of the detector can be summarized as follows: (1) Single 100 kton “boiling” cryogenic tanker at atmospheric pressure for a stable and safe equilibrium condition (temperature is constant while Argon is boiling). The evaporation rate is small (less than  $10^{-3}$  of the total volume per day given by the very favorable area to volume ratio) and is compensated by corresponding refilling of the evaporated Argon volume. (2) Charge imaging, scintillation and Cerenkov light readout for a complete (redundant) event reconstruction. This represents a clear advantage over large mass, alternative detectors operating with only one of these readout modes. The physics benefit of the complementary charge, scintillation and Cerenkov readout are being assessed. (3) Charge amplification to allow for very long drift paths. The detector is running in bi-phase mode. In order to allow for drift lengths as long as  $\sim 20$  m, which provides an economical way to increase the volume of the detector with a constant number of channels, charge attenuation will occur along the drift due to attachment to the remnant impurities present in the LAr. This effect can be compensated with charge amplification near the

anodes located in the gas phase. (4) Absence of magnetic field, although this possibility might be considered at a later stage. Physics studies [13] indicate that a magnetic field is really only necessary when the detector is coupled to a Neutrino Factory.

The cryogenic features of the proposed design are based on the industrial know-how in the storage of liquefied natural gases (LNG,  $T \simeq 110$  K at 1 bar), which developed quite dramatically in the last decades, driven by the petrochemical and space rocket industries. LNG are used when volume is an issue, in particular, for storage. The technical problems associated to the design of large cryogenic tankers, their construction and safe operation have already been addressed and engineering problems have been solved by the petrochemical industry. The current state-of-the-art contemplates cryogenic tankers of  $200000 \text{ m}^3$  and their number in the world is estimated to be  $\sim 2000$  with volumes larger than  $30000 \text{ m}^3$  with the vast majority built during the last 40 years. Technodyne International Limited, UK [16], which has expertise in the design of LNG tankers, has been appointed to initiate a feasibility study in order to understand and clarify the issues related to the operation of a large underground LAr detector. A final report is expected soon.

A schematic layout of the inner detector is shown in Figure 4. The detector is characterized by the large fiducial volume of LAr included in a large tanker, with external dimensions of approximately 40 m in height and 70 m in diameter. A cathode located at the bottom of the inner tanker volume creates a drift electric field of the order of 1 kV/cm over a distance of about 20 m. In this field configuration ionization electrons are moving upwards while ions are going downward. The electric field is delimited on the sides of the tanker by a series of ring electrodes (race-tracks) placed at the appropriate potential by a voltage divider.

The tanker contains both liquid and gas Argon phases at equilibrium. Since purity is a concern for very long drifts of 20 m, we assume that the inner detector could be operated in bi-phase mode: drift electrons produced in the liquid phase are extracted from the liquid into the gas phase with

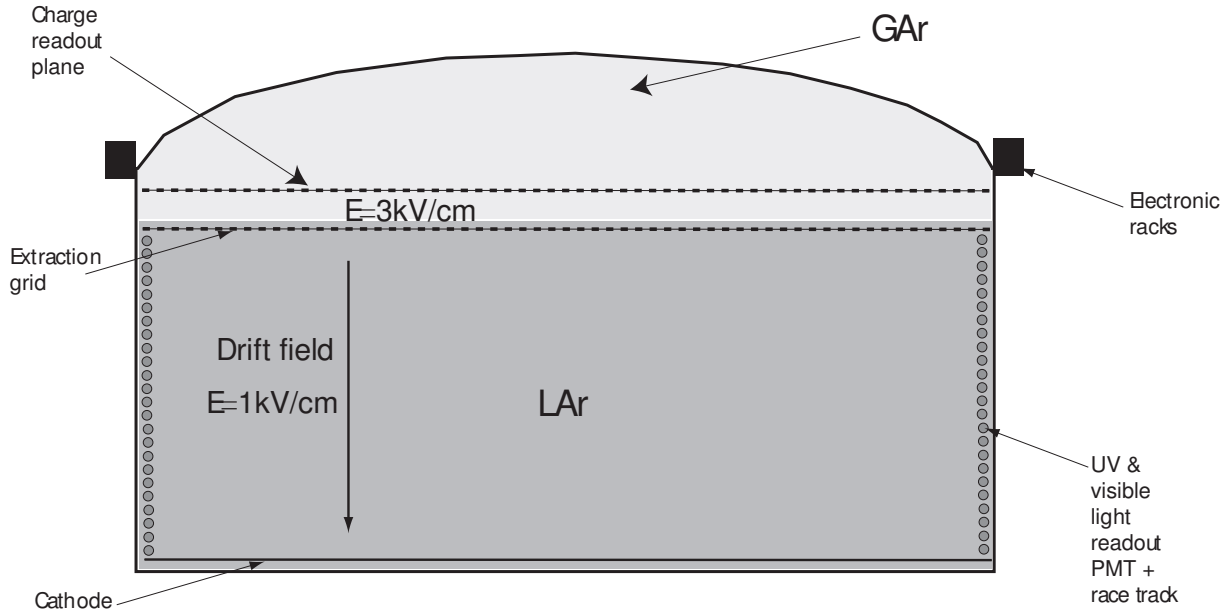


Figure 4. Schematic layout of a 100 kton liquid Argon detector. The race track is composed of a set of field shaping electrodes.

the help of a suitable electric field and then amplified near the anodes. In order to amplify the extracted charge one can consider various options: amplification near thin readout wires, GEM [17] or LEM [18]. Studies that we are presently conducting show that gain factors of 100-1000 are achievable in pure Argon [19]. Amplification operates in proportional mode. Since the readout is limited to the top of the detector, it is practical to route cables out from the top of the dewar where electronics crates can be located around the dewar outer edges.

After a drift of 20 m at 1 kV/cm, the electron cloud diffusion reaches approximately a size of 3 mm, which corresponds to the envisaged readout pitch. Therefore, 20 m practically corresponds to the longest conceivable drift path. As mentioned above, drifting over such distances will be possible allowing for some charge attenuation due to attachment to impurities. If one assumes that the operating electron lifetime is at least  $\tau \simeq 2$  ms (this is the value obtained in ICARUS T600 detector during the technical run [9] and better values of up to 10 ms were reached on smaller prototypes during longer runs), one then expects an

attenuation of a factor  $\sim 150$  over the distance of 20 m. This loss will be compensated by the proportional gain at the anodes. We remind that the expected attenuation factor (compensated by the amplification) will not introduce any detection inefficiency, given the value of  $\sim 6000$  ionization electrons per millimeter produced along a minimum ionizing track in LAr.

In addition to charge readout, one can envision to locate PMTs around the inner surface of the tanker. Scintillation and Cerenkov light can be readout essentially independently. LAr is a very good scintillator with about 50000  $\gamma$ /MeV (at zero electric field). However, this light is essentially distributed around a line at  $\lambda = 128$  nm and, therefore, a PMT wavelength shifter (WLS) coating is required. Cerenkov light from penetrating muon tracks has been successfully detected in a LAr TPC [8]; this much weaker radiation (about 700  $\gamma$ /MeV between 160 nm and 600 nm for an ultrarelativistic muon) can be separately identified with PMTs without WLS coating, since their efficiency for the DUV light will be very small.



## 4.2. R&D towards a 100 kton liquid Argon detector

Studies are underway and planned with the aim of identifying the main issues of the future systematic R&D and optimization activities[20]:

(1) **The study of suitable charge extraction, amplification and collection devices:** We are continuing an R&D study to further optimize the technique for charge extraction, amplification and collection. We are seeking a solution which yields gains between 100 and 1000 in pure Argon, which is electrically and mechanically stable, and easy to be mass produced.

(2) **The understanding of charge collection under high pressure as expected for events occurring at the bottom of the large cryogenic tanker:** We are constructing a small chamber which will be pressurized to 3-4 bar to simulate the hydrostatic pressure present at the bottom of a future 100 kton tanker. We intend to check that the drift properties of electrons are not affected at these pressures.

(3) **The realization of a 5 m long detector column:** We are constructing a column-like dewar 6 m long and 40 cm in diameter which will contain a 5 m long prototype LAr detector. The device will be operated with a reduced electric field value in order to simulate very long drift distances of up to about 20 m. Charge attenuation and amplification will be studied in detail together with the adoption of possible novel technological solutions. In particular, several options are being studied for both the HV field shaping electrodes and for the readout devices.

(4) **The study of LAr TPC prototypes immersed in a magnetic field.:** Liquid Argon imaging provides very good tracking with  $dE/dx$  measurement, and excellent calorimetric performance for contained showers. This allows for a very precise determination of the energy of the particles in an event. This is particularly true for electron showers, which energy is very precisely measured.

The possibility to complement these features with those provided by a magnetic field has been considered and would open new possibilities[13, 15]: (a) charge discrimination, (b) momentum measurement of particles escaping the detector

(*e.g.* high energy muons), (c) very precise kinematics, since the measurements are multiple scattering dominated (*e.g.*  $\Delta p/p \simeq 4\%$  for a track length of  $L = 12\text{ m}$  and a field of  $B = 1T$ ).

The orientation of the magnetic field is such that the bending direction is in the direction of the drift where the best spatial resolution is achieved (*e.g.* in the ICARUS T600 a point resolution of  $400\text{ }\mu\text{m}$  was obtained). The magnetic field is hence perpendicular to the electric field. The Lorentz angle is expected to be very small in liquid (*e.g.*  $\approx 30\text{ mrad}$  at  $E = 500\text{ V/cm}$  and  $B = 0.5T$ ). Embedding the volume of Argon into a magnetic field would therefore not alter the imaging properties of the detector and the measurement of the bending of charged hadrons or penetrating muons would allow a precise determination of the momentum and a determination of their charge.

The required magnetic field for charge discrimination for a path  $x$  in the liquid Argon is given by the bending and the multiple scattering contribution. The requirement for a  $3\sigma$  charge discrimination implies[15]:

$$B \geq \frac{0.2(T)}{\sqrt{x(m)}} \quad (1)$$

For long penetrating tracks like muons, a field of  $0.1T$  allows to discriminate the charge for tracks longer than 4 meters. This corresponds for example to a muon momentum threshold of  $800\text{ MeV/c}$ . Hence, performances are very good, even at very low momenta.

Unlike muons or hadrons, the early showering of electrons makes their charge identification difficult. The track length usable for charge discrimination is limited to a few radiation lengths after which the showers makes the recognition of the parent electron more difficult. In practice, charge discrimination is possible for high fields  $x = 1X_0 \rightarrow B > 0.5T$ ,  $x = 2X_0 \rightarrow B > 0.4T$ ,  $x = 3X_0 \rightarrow B > 0.3T$ . From simulations, we found that the determination of the charge of electrons of energy in the range between 1 and 5 GeV is feasible with good purity, provided the field has a strength in the range of 1 T. Preliminary estimates show that these electrons exhibit an average curvature sufficient to have electron charge



discrimination better than 1% with an efficiency of 20%. Further studies are on-going.

An R&D programme to investigate a LAr drift chamber in a magnetic field was started in 2001. The goal is to study the drift properties of free electrons in LAr in the presence of a magnetic field and to prove that the detection capabilities are not affected. We have built a small liquid Argon TPC (width 300 mm, height 150 mm, drift length 150 mm) and placed it in the recycled SINDRUM-I magnet<sup>2</sup> which allows us to test fields up to 0.5 T. The ongoing test programme includes (1) checking the basic imaging in B-field (2) measuring traversing and stopping muons (3) test charge discrimination (4) check Lorentz angle.

**(5) The further development of the industrial design of a large volume tanker able to operate underground :** The study initiated with Technodyne UK should be considered as a first “feasibility” study, meant to select the main issues that will need to be further understood and to promptly identify possible “show-stoppers”. If successful, we expect to continue this study by more elaborated and detailed industrial design of the large underground tanker including also the details of the detector instrumentation. The cost of the full device will be estimated as well. At this preliminary stage a large mass LAr detector appears to be a cost effective option.

**(6) The study of logistics, infrastructure and safety issues related to underground sites :** We are making preliminary investigations with two “generic” geographical configurations: (i) a tunnel-access underground laboratory, (ii) a vertical mine-type-access underground laboratory. Early considerations show that such sites correspond to interesting complementary options. Concerning the provision of LAr, a dedicated possibly not underground but nearby air-liquefaction plant is foreseen. Technodyne has started investigating the technical requirements and feasibility of such a facility.

These R&D studies could lead to the necessity of a 10% full-scale prototype, which could be placed at shallow depth, used as an engi-

neering prototype with a physics program on its own[20,24].

## 5. Conclusions and outlook

The Argon Time Projection Chamber (LAr TPC) technology, whose basic R&D work has been successfully conducted by the ICARUS Collaboration, is a mature technique with great potentials. We have outlined a strategy for next generation experiments on neutrino and astroparticle physics based on the use of this technique at different detector mass scales.

From our general considerations, we can conclude the following points:

(a) a 100 kton liquid Argon TPC based on the tentative design outlined above seems technically sound and would deliver extraordinary physics output (sometimes called “megaton physics”). This device could effectively compete with giant 0.5-1 Megaton water Cerenkov detectors being proposed for future precision studies of the neutrino mixing matrix and for nucleon decay searches[14]. Coupled to future Superbeams[21], Betabeams or Neutrino Factories[13,22] it could greatly improve our understanding of the mixing matrix in the lepton sector with the goal of measuring the CP-phase, and in parallel it would allow to conduct astroparticle experiments of unprecedented sensitivity[20,23]. The main design features include the possibility of a bi-phase operation with charge amplification for long drift distances, an imaging plus scintillation plus (possibly) Cerenkov readout for improved physics performance, and a very large boiling industrial cryostat (LNG technology). The main issues are related to finding a practical underground location – deep or shallow depth depending of physics goals – and an appropriate funding on the scale. A rough estimate of the cost has been elaborated[24].

(b) a 10% full-scale, cost effective prototype of the design outlined above on the scale of 10 kton could be readily envisaged as an engineering design test with a physics program of its own, directly comparable to that of Superkamiokande. This would provide a direct and probably final demonstration of the advantages of a very large

<sup>2</sup>The magnet was kindly lend to us by PSI, Villigen.

scale liquid Argon TPC compared to other existing or planned techniques. A rough estimate of the cost has been elaborated[24].

(c) A 100 ton detector in a near-site of a long-baseline facility is a straight forward and very desirable application of the technique. For example, the approved T2K experiment in Japan or other beams in the US might provide the ideal conditions to study with high statistical accuracy neutrino interactions on liquid Argon in the very important energy range around 1 GeV. This is a mandatory step in order to be able to handle high statistics provided by large detectors. A prototype of a 100 ton detector could provide a tool to study calorimetric (electromagnetic and hadronic) response in a charged particle beam or be readily placed in an existing neutrino beam.

Work is in progress along these lines of thoughts.

There is a high degree of interplay and a strong synergy between small and large mass scale apparatuses, the very large detector needing the small one in order to best exploit the measurements with high statistical precision that will be possible with a large mass. We believe (and hope) that small and very large LAr detectors will play significant and important roles in the future.

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